3. Paired Watershed Study

3.1 Introduction

The NMP included a "paired-watershed" study (Clausen and Spooner, 1994). Land treatment measures (Best Management Practices, also known as BMPs) were installed in Chumash watershed during the period 1995 through 1997. Walters Creek has continued to be the control watershed with no BMPs. Figure 3.1 shows the Chumash Creek and Walters Creek watersheds.

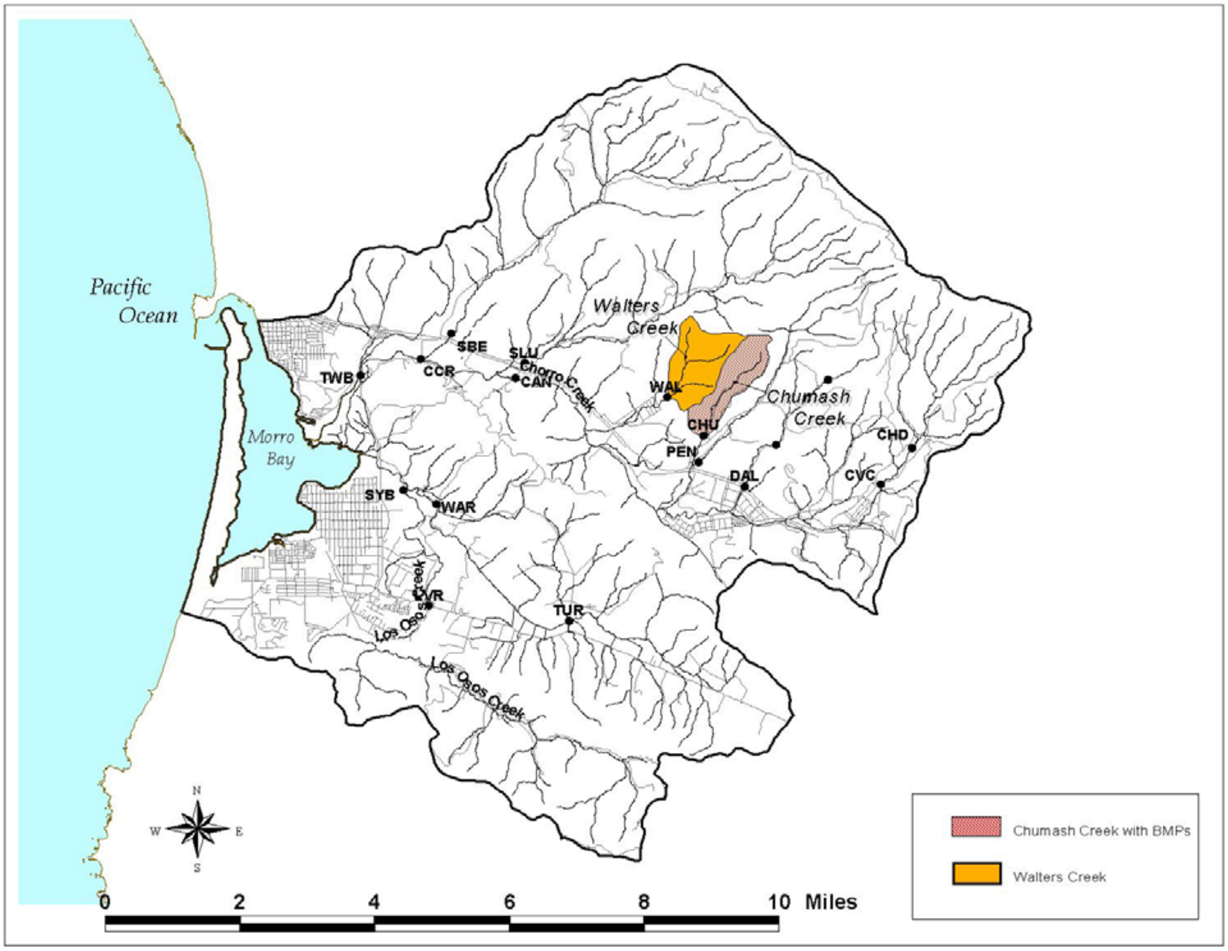


Figure 3.1 Chumash Creek and Walters Creek watersheds.

BMPs include; fencing the entire riparian corridor, creating smaller pastures for better management of cattle grazing, and grazing rotations through these pastures, providing water distribution to each of the smaller pastures through spring and well development and installation of water troughs, installing waterbars and culverts on farm roads, removing an in-stream stock pond damaged during winter storms of 1995 and stabilizing the newly-contoured stream banks, and planting native riparian trees along selected stream banks (Shotwell, 2000). Walters, Chumash, and a third watershed, Pennington, are contained in the northeast part of the Escuela Ranch, one of the western ranches on Cal Poly land (Fig. 3.2). The three watersheds are managed for cattle grazing as part of the Escuela Enterprise project, described in more detail below.

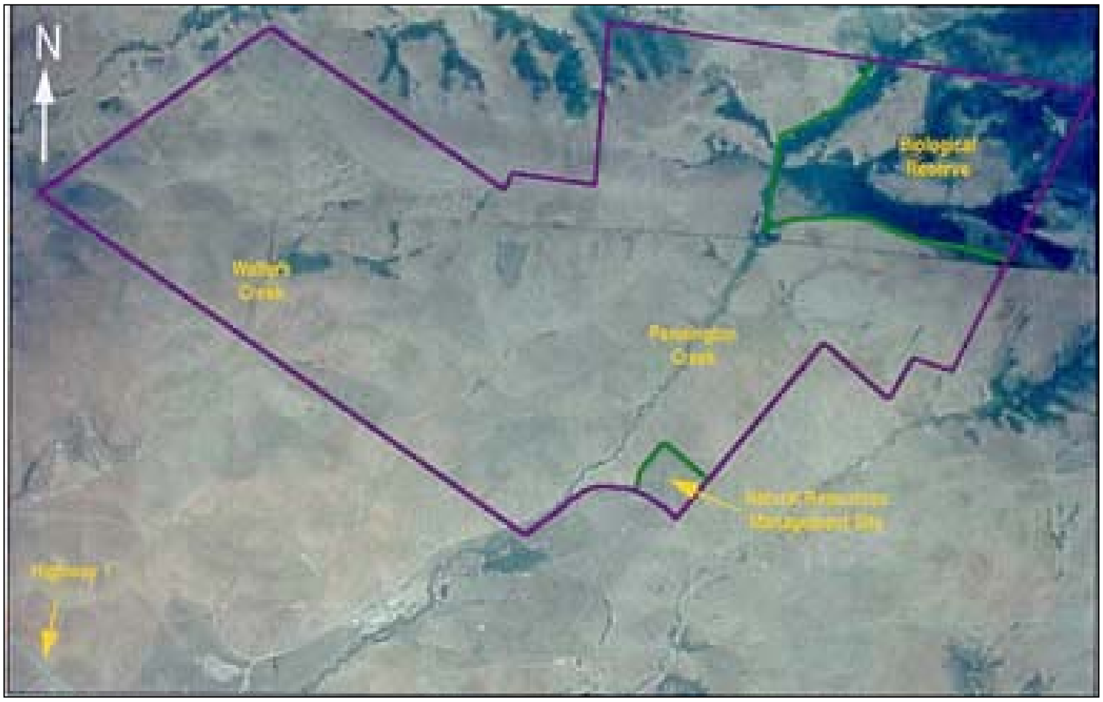


Figure 3.2. Escuela Ranch. Figure courtesy of Cal Poly Kennedy Library Archives (http://polyland.lib.calpoly.edu/overview/Archives/nieto/chorro.html)

Installation of the BMPs in Chumash watershed were designed to result in significant improvements to water quality of creek waters, rangeland productivity, riparian vegetation cover, and streambank stability. A 50 percent reduction in sediment discharge from Chumash Creek was anticipated. Specific objectives were (1) demonstrate a variety of simple, cost-effective BMPs, accessible to landowners, for controlling soil erosion and sediment, (2) successfully reduce sediment and turbidity levels, water temperature, fecal coliform, and nutrient concentrations (3) maintain healthy levels of dissolved oxygen (4) improve riparian and in-stream habitat, benthic invertebrate assemblages, and rangeland quality (5) promote multiple use objectives and demonstrate that grazing is compatible with revegetation and habitat improvement, and (6) achieve enterprise profitability linked to sound resource management.

Chumash Creek and Walters Creek sub-watersheds were chosen for the paired watershed study because of their many similarities. The sub-watersheds are similar in size, shape, aspect, slope, elevation, soil type, climate, and vegetation. Chumash Creek Watershed is 400 acres and adjacent Walters Creek Watershed is 480 acres. Subwatershed aspects are southwest facing and elevation ranges from 300 to700 feet. Vegetation is mainly naturalized annual grasses with native perennial grasses and forbs sporadically distributed on the rolling hillsides. The physical similarities between sub-watersheds reduced the effects of environmental variation within the study; the sub-watersheds were well suited for the experiment.

Chumash watershed was used for army training during World War II, and the lower section near the flume was an army disposal area many years before the study began. Additionally in 1988 following a drought, stock ponds were constructed in several small creeks on Cal Poly ranchland (including two on Chumash Creek), by constructing earthen dams in the channels. The construction of these undoubtedly disturbed the vegetation in the immediate area of construction. Then, the dams failed in the 1991-92 rainy season, again presumably disturbing vegetation in the immediate area of the failure. Due to backwater effects on the flume, post-BMP vegetation was removed below the flume. These activities were most likely less profound as the military operations.

At the beginning of the project, Chumash and Walters were, visually, in comparable condition with respect to stream channel condition and approximate amount of bare ground vs. vegetative cover (Fig. 3.2). Erosion in both creeks was mainly by streambank sloughing, with bare soil exposed in scars. At the beginning of the water quality-monitoring period, Chumash Creek typically produced more sediment during a given storm than Walters Creek.

Figure 3.2. Photographs of Walters (left) and Chumash (right) Creeks, with scars caused by stream bank sloughing evident. (Vegetation is green in Chumash because the photograph was taken during the rainy season; Walters was photographed during the dry season).

Chumash Creek was chosen as the “treatment” creek for Best Management Practices (BMPs) because of easier access for BMP implementation and water development. Accessibility was an issue for seasonal maintenance of road improvements, and for cattle management. Providing adequate water for cattle was very important, since their access to the stream channels was limited and controlled. Two springs in Chumash watershed were developed, and pipelines installed to convey water to troughs for the cattle. The springs proved to be inadequate as reliable sources of water especially during summers, and in 1999, two horizontal wells were drilled.

In order to understand the relationships of the creeks and watersheds to one another and to test for differences that were expected to occur due to BMP implementation, the study was divided into two time periods, pre-BMP and post-BMPs. The pre-BMP period, 1993 through 1996, was used to develop a statistical understanding of the relationship of the creeks to one another and to environmental fluctuations. The post-BMP time period, 1997-2001, was used to statistically understand the relationship of the creeks to one another and the effects of BMPs. Rangeland BMPs were expected to improve water and habitat quality parameters at Chumash Creek.

3.1.1 Best Management Practices Implementation

BMPs fell within four categories of rangeland management practices: livestock fencing and water development, streambank stabilization, road improvement, and grazing management. Each BMP category contains individual BMPs that were intended to address the sources of nonpoint source pollution (Shotwell, 2000). Categories and corresponding BMPs are listed below, with year of implementation in parentheses.

The fencing and water development category included the following BMPs:
- Installation of spring boxes and water storage tanks (1994 through 1996),
- Installation of upland watering troughs (1994 through 1996),
- Installation of water supply pipelines to the troughs (1995 through 1996),
- Subdivision of existing upland pastures into smaller pastures compatible with water trough placement and accessibility and grazing rotations (1995 through 1996), and
- Installation of riparian pastures, compatible with revegetation objectives (1995 through 1996).

The streambank stabilization category included these BMPs:
- Planting of oaks and sycamores, and providing supplemental drip irrigation (1996 through 1997),
- Bioengineered revegetation using willow stakes (1996 through 1997),
- Critical area seeding of disturbed areas (1996 through winter 1999),
- Recontouring of an upper relic instream stock pond (1995 through 1996),
- Removal and stabilization of a relic lower instream stock pond (1996 through 1997), and
- Channel headcut and gully repair (1995 through 1996).

The road improvement category included the following:
- Installation of water bars (1995 through 1996),
- Repair of existing culverts and installation of new culverts (1995 through 1996),
- Filling degraded road beds with red-rock gravel (1995 through 1996),
- Road abandonment and elimination of seasonal road re-grading where feasible (begun 1995, ongoing),
- Restrictions on winter (rainy season) access (begun 1995, ongoing), and
- Seasonal maintenance and operations, to control runoff and limit re-grading of roads damaged from winter rains (begun 1995, ongoing).

The grazing management category included these BMPs:
- Riparian exclusion and deferred riparian grazing (pastures established in 1995, ongoing), and
- Intensive rest-rotation grazing, utilizing the pasture subdivisions (pastures established in 1995, ongoing). Small pastures range in size from 23 to 130 acres, with average size about 45 acres.

Total project costs were $227,615, of which $130,000 was provided by a cost share grant from a USEPA 319(h) grant (Shotwell, 2000). The remaining $97,615 was provided by direct funding and "in-kind" contributions from Cal Poly (Shotwell, 2000). Itemized costs were:

Administration and Reports	$27,266
Management Plan	3,500
Water development and fencing`	140,675
Revegetation (bank stabilization)	16,000
Road treatment	19,239
Field trips, landowners	925
Maintenance	20,000
Total	$227,615

3.1.2 Grazing Management

Chumash, Walters, and Pennington watersheds are within the Escuela Ranch (Fig. 3.1). The Escuela Ranch plays a critical role in the Animal Science Department for the training of students in the management and stewardship of cattle and rangeland. The ranch is the site of a 160-cow commercial cow/calf herd, and virtually the entire ranch is maintained in the grazing program. Cattle are kept together and managed as one herd, in both the Chumash Creek and Walters Creek watersheds, as well as an additional watershed (Pennington Creek) that is not part of the paired watershed study. The two primary goals for the Escuela Ranch are education and sustainability. The education of Animal Science – as well as other majors' - students is achieved at the Escuela Ranch through many avenues including as a laboratory resource for Animal Science courses and as a research resource for Senior Projects. However, the greatest educational experience is available to students through the Escuela Enterprise. This enterprise is designed such that a group of students leases the cattle from the Cal Poly Foundation, and manages the herd throughout an entire fiscal year. Through this experience, the students are in charge of calving, feeding, and breeding decisions, and participate in all of the health aspects of a commercial cow/calf herd. Students learn about different grazing management methods. The enterprise allows students to apply technologies and management practices discussed in the classroom in the learn-by-doing philosophy that has embodied Cal Poly Education for nearly 100 years.

The cowherd is primarily Angus based, and the breeding decisions are based on consistency, desirable carcass characteristics, and rapid growth. Cows calve between mid-October and the end of December, are bred in early February, and calves are weaned around the first part of June. At weaning all calves are removed from the ranch with some heifers kept at a different ranch for replacements and the remaining calves sold. Feed supplementation is used as needed during the last trimester of gestation and the first month of lactation depending on rainfall and forage availability.

The other major goal for the ranch is sustainability. Sustainability is viewed as both improvement of the environment and profitability of the enterprise. Improvement of the environment is determined through increased forage production leading to decreased erosion and decreased supplementation costs for the cowherd, and increased plant and animal biodiversity. Together the unique educational opportunity and efforts in sustainability will ensure the future of the ranch and the enterprise.

The grazing method utilized on the ranch is classified as rest/rotational grazing. Rest/rotational grazing emphasizes the rest period between grazing, which means that animals graze and are then moved to another pasture to allow a period of rest for the plants within each pasture before the animals return to graze. An increase in the number of pastures, i.e. smaller pastures, allows for more rest in any rotation. Therefore, root systems have more time to regenerate themselves before grazing. As root systems grow, more nutrients should be absorbed from the soil increasing total plant growth, hold more moisture within the soil, and decreasing runoff. The paired watershed study is a comparison between rest/rotation and rest/rotation, with the treatment consisting of smaller pasture size, and more numerous pastures, in Chumash - thus more total rest in Chumash.

When water quality, range, and stream data collection began in 1993, the Walters watershed had four pastures ranging in size from 131 acres to 311 acres. This pasture design has not changed throughout the study and acts as a control with fewer large pastures. Therefore, when cattle graze in this watershed, they graze more time in each pasture and each pasture gets less rest during each rotation.

In 1993 (pre-BMP) the Chumash watershed was subdivided into only two pastures of 287 acres and 290 acres. By the end of 1995, most of the division of the two original pastures into 14, with some traditional barbed wire fencing, but mainly electric fencing was completed. In 1996 and subsequent years cattle have been rotated through 14 pastures in the Chumash watershed ranging in size from 15 to 130 acres with most of the pastures between 25 and 68 acres. Two of the 14 pastures were established as riparian pastures that are only grazed one to three days per year and only during the dry season. Cattle spend less time in any single pasture with more rest for each pasture.

The biggest challenge in running cattle at Escuela, as with any ranch on California's Central Coast, is the availability of water for the cattle. With the division of the pastures in 1994-95, water sources were developed, and water troughs were placed throughout the ranch to ensure that cattle would be watered. However, neither of the springboxes that feed the watertanks was sufficient to ensure a continuous supply of water, particularly during the summer months. To remedy this challenge, two horizontal wells were drilled into the sides of the hills on the ranch, and these wells provide water for the previously existing tanks. This development, completed in Fall 1999, has dramatically improved the flexibility for grazing throughout the year. This improves forage utilization, and aids in proper range management.

3.1.3 Cattle Management Records

Since 1994 the location of the cattle (by pasture identification) and number of cattle within the pasture have been recorded on a daily basis). Cattle were rotated through Walters and Chumash watersheds, and also through the Pennington Creek watershed, which was not included in the study. Pennington Creek was included in cattle management because of the needs of the Escuela Enterprise project. In general, cattle spent about one-third of their time in each watershed. With respect to the paired watersheds, cattle have been allowed to graze in each pasture in all watersheds, with the grazing and rest times dependent on several variables. These variables included rainfall; forage growth; type of forage; number of animals; stage of animal production; and stage of plant growth. Generally in times of fast plant growth cattle were grazed a shorter period of time per pasture with less rest (fast growth = fast moves). When plant growth slowed down cattle were left longer to graze in each pasture with a longer rest period (slow growth = slow moves). During periods of fast growth, forage is quickly replaced without depleting root reserves. During periods of slow growth, slower rotations allow plants in each pasture a longer recovery time, post grazing.

Implementation of the intensive rest/rotational grazing system in Chumash did not begin until 1995, and was not fully implemented until 1996 with the completion of the fencing and water systems. Throughout the duration of this project, cattle movement was at the discretion of the administrators of the Escuela Enterprise project, and primarily to serve the needs of the enterprise.

Statistical Analyses

Analysis of variance (ANOVA) was used to determine if grazing days, rest days, and animal unit day (AUD) per acre were truly different, between Walters and Chumash watersheds. The ANOVA model for all variables was:

$$Y_{ijk} = \mu + R_i + T_j + RT_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} was the observation (mean grazing days per pasture, mean rest days per pasture, or AUD/acre) for the j-th treatment during the i-th year, where i = 1996, 1997, 1998, 1999, 2000, 2001; and j = treatment watershed or control watershed. T_j was the j-th treatment effect (a fixed effect), R_i was the year effect (a fixed effect), and ε_{ijk} was the residual error due to the (i, j, k)-th observation assumed to be randomly normally distributed with mean 0 and variance σ^2, where σ^2 was estimated by the ANOVA mean square error.

With the exception of 2001, animal unit days per acre did not differ ($p > .05$) by watershed for any of the years tested (1996-2000; Table 3.1). Grazing data were collected and analyzed to correspond to the fiscal year, corresponding to the rain year. In 2001, data only included dates from January through June, having been collected during storm events. Therefore, there was inadequate data to completely test the effect of BMP implementation on grazing for the partial season. There appeared to be an increase in the animal unit days per acre in the treatment watershed, although this trend was not significant ($p>.05$). The increase in AUD/acre indicates an increase in productivity due the implementation of BMPs.

Table 3.1. Yearly grazing comparison (1996-2001) of the Walters and Chumash watersheds after fencing of Chumash watershed was completed

	AUD/acre		Grazing Days[1]		Rest Days[1]	
Year	Walters	Chumash	Walters	Chumash	Walters	Chumash
1996	27.2	35.1	41.0[a]	11.4[b]	324.0[a]	353.6[b]
1997	29.9	31.9	43.5[a]	8.3[b]	321.5[a]	356.7[b]
1998	32.1	24.8	54.0[a]	8.9[b]	311.0[a]	356.1[b]
1999	28.2	34.5	43.7[a]	8.0[b]	321.3[a]	357.0[b]
2000	29.3	45.2	34.0[a]	9.3[b]	331.0[a]	355.7[b]
2001 (Jan-June)	16.0	48.5	12.7[a]	5.9[b]	169.3[a]	176.1[b]

*Grazing and rest days are averages per pasture within each watershed
[1]Superscripted letters a and b denote that differences between the two watersheds are significant ($p<.01$).

The number of days grazed per pasture did continue to be significantly ($p>.05$) affected by treatment. Post BMP, pastures in the Chumash watershed had fewer average days grazed compared with pastures in the Walters watershed (on a per pasture basis). These data are depicted in Table 3.1 and Figure 3.3. Figure 3.3 compares grazing days per pasture between Walters and Chumash watersheds. The number of days cattle spent in each pasture in Chumash watershed was less, but days per watershed was about the same. We could not make acre-per-acre comparisons between the two watersheds, because in a large pasture, cattle can select where they prefer to spend most time. They generally will congregate and linger where there is fresh forage, shade, and water. In smaller pastures the cattle's ability to be selective is restricted. Thus, out of 400 acres as one large pasture, cattle will use some fraction of the 400 acres. If the 400-acre pasture is divided into 10 4-acre pastures, and the cattle are rotated through these, it is more likely the cattle will use a greater fraction of the 400 acres.

Finally, supplementation costs continued to be lower than prestudy data would indicate. However, the average supplementation costs per cow was greater during 1999-2000 than the previous year. This is most likely due to the poorer forage weather, particularly rainfall, received in winter 2000. The total number of cows maintained in the Escuela herd continues to be greater than pretrial numbers, at approximately 160 cows. These data are represented in Figure 3.4.

One of the primary concerns in a low-cost cattle operation is the supplemental feed costs required to maintain the herd throughout the year. At best, a herd could be maintained with little more than simply mineral supplementation. However, it is very difficult to eliminate energy and protein supplementation because of the increased demand for nutrients by cows at different points during their productive cycle. As seen in Figure 3.4, the supplementation costs per cow in the Escuela Enterprise project have decreased dramatically during the study. The "scatter" is due to the unpredictable rainfall that occurs at the ranch from year to year.

During the pre-BMP period, cattle were grazed similarly between the Chumash, Walters, and Pennington watersheds. Post-BMP, cattle movement remained the same in Walters and Pennington watersheds, but rotated more intensively through Chumash. Not enough time has elapsed to see any real effect on the cattle. Rainfall for 1995 through 2000 was above average and should improve cattle production regardless of grazing management. Perhaps five to ten more years, with some being dry years, are needed to measure any effect on weaning weights, supplemental feed costs, or condition scores of the cows. Additionally, increased forage production may lead to greater cow carrying capacity. Carrying capacity was not specifically addressed in this project. However, differences in plant and stream data from grazing differences between the two watersheds, may allow for hypotheses regarding animal production.

Since tests of carrying capacity or quantification of cattle benefits were not a part of this study, rotations of the cattle through a third watershed (Pennington) did not affect the interpretations of the comparative study of Walters and Chumash Creeks, with respect to water quality, rangeland properties, and stream channel assessments.

Other general observations have been made as far as the behavior of the cattle and labor. The cattle on the ranch tend to be very docile and easy to move. This may be a result of more human contact, which is needed for the movement under the rest/rotational system. When cattle are moved, usually "calling" the cattle by vocalization is all that is required. The cattle seem to have learned that people mean movement to new feed. This movement does mean more time with the cattle, which could result in an increase in labor. However, this increase in time with the cattle also means more time for observation of health and general management of the cows.

A final observation made in recent years was the location of undesirable plant species. The only concentration of undesirables (mustard, thistles, etc.) was in the riparian pastures of Chumash. These two pastures have been limited to grazing one to three days per year only during the dry season to decrease activity in the creek when it was raining. Perhaps if grazing is allowed more often or at different times in the future the undesirables could be reduced as they are in the rest of the ranch, apparently due to animal impact. During the last 8 months, hay was fed on top of the areas of thistle in the riparian areas. We hypothesize that the increased animal impact will suppress growth of the undesirable plant species. However, it is too early to determine the effectiveness of this technique.

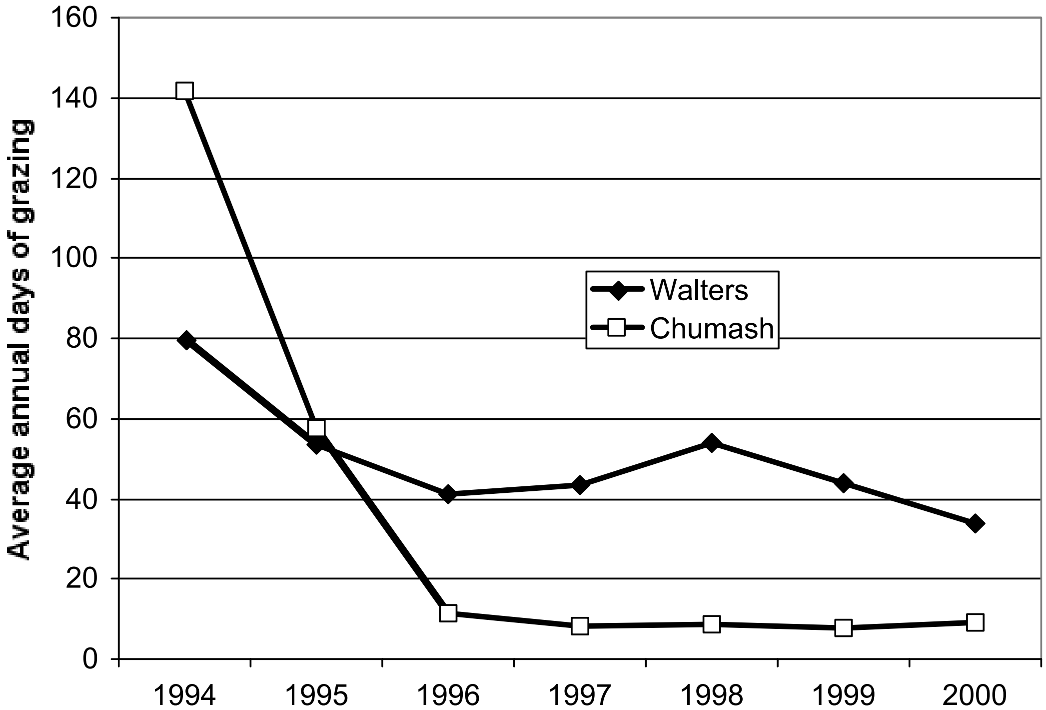


Figure 3.3. Average annual days of grazing per pasture.

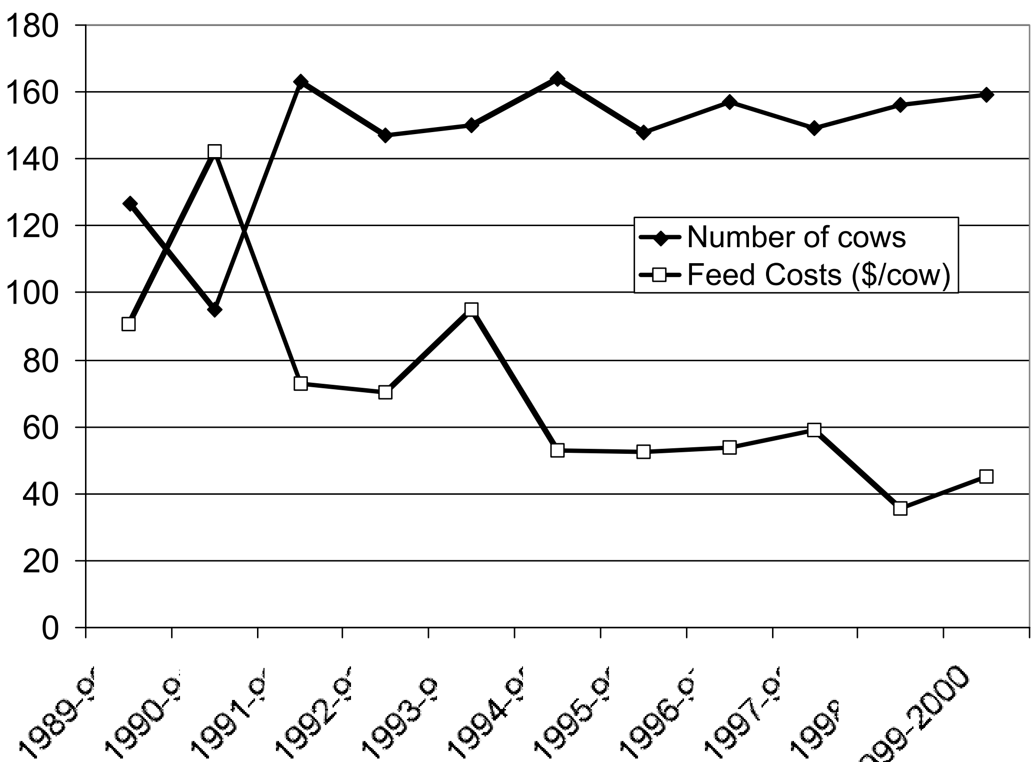


Figure 3.4. Number of cows and average annual per cow supplemental feed costs.

The original design of the study did not allow for rigorous determination of the effects of BMP implementation on productivity of the rangeland, as productivity relates to grazing animals. This can be attributed to two factors:

(1) Cattle used in the study grazed the entire ranch, including both Walters and Chumash as well as Pennington. Therefore, effects of the BMPs on feed costs were dampened by the increased availability of feed in all three of the watersheds. It was assumed that as forage availability increased in the Chumash (treatment) watershed, the energy availability increased in the remaining 2 watersheds as the cattle acquired a greater level of nutrient intake in each. A more appropriate experimental design would have maintained the 2 watersheds as separate compartments, in which separate herds of cattle would be grazed simultaneously. In this design, supplemental feed would be differentially determined between watersheds. Additionally, body condition scores could be estimated throughout the year, and impact of BMP implementation on seasonal forage availability would be determined empirically.

(2) The Escuela ranch was, at the beginning of the study, in much better condition, and more intensively managed than the vast majority of California ranches. For example, even the control watershed (Walters) consisted of 4 pastures through which cattle were rotated, albeit infrequently. Therefore, the proportion of rest days to grazed days was already much better than most grazing systems. In a traditional western cattle ranch, no crossfencing would be available, and the grazing system would be a complete open grazing system.

The lack of study in forage productivity did not affect water quality results or interpretations.

3.2 Methods

3.2.1 Climate, Streamflow, and Event-based Water Quality

Water quality and streamflow monitoring were accomplished with instrumented gauging stations installed at the outlet of each paired watershed. Gauging stations were installed at a location in each stream channel to allow collection of comparable and representative continuous streamflow and water quality samples (Price and Tyzzer, 1993). Each gauging site consisted of the same components: a Parshall flume with two stilling wells instrumented with floats and potentiometers allow for five-minute stage readings, a Campbell Scientific CR10 datalogger, and a solar panel used to augment the battery power supply. An automated water quality sampler at each gauging station was used to collect water samples, which were taken to a laboratory, refrigerated, and later analyzed for suspended sediment (filterable solids), turbidity, and conductivity.

Climate data were measured at a centrally located weather station representative of average conditions for the paired watersheds. The weather station was completely operational during the life of the project. Climatic data were downloaded monthly and archived. Additionally, two tipping bucket rain gauges were located in each of the paired watersheds. A gauge was located on the roof of each of the instrument sheds at the gauging stations. Both of these gauges logged precipitation data to the same electronic data loggers used for streamflow data. The locations of these two gauges were chosen because both sites are relatively protected from wind and because of easy access. The on-site rainfall data was considered to be more representative of rainfall received by each watershed, a more robust statistical parameter, and more useful for hydrologic modeling purposes, than the centrally located station.

Water level potentiometers were calibrated each fall. Additional ocular stage readings throughout the season ensured that water level instrumentation remained calibrated. Sediment buildup in the stilling wells of the Chumash and Walters flumes was removed on an annual or as-needed basis. Station maintenance included bimonthly retrieval of data from data storage modules using a laptop computer, inspection of sampling intake siphons and automated sampler operation, and maintenance of the power sources. Additionally, a longitudinal profile below each flume was surveyed every other year, to assure that the aggradation below the flume did not compromise the stream stage data. Continuous stage measurements were retrieved from the data recorder at each flume using the PC300 program. The data were reformatted in Microsoft Excel, where stage was converted to streamflow, expressed in ft^3/sec (cfs), calculated using discharge rating formulas supplied by the manufacturer of each flume.

In the event-based study, the five-minute streamflow data were summarized over a 30-minute time step to correspond to the 30-minute water quality-sampling interval for the events that were sampled.

3.2.2 Event-Based Water Quality Monitoring

Event-based water samples were collected every 30 minutes by Sigma automatic samplers during storm events that generated sufficient runoff to submerge the instream sampling intakes. Paired event-based water quality samples from Chumash Creek and Walters Creek watersheds were analyzed for turbidity, electrical conductivity, and suspended sediment concentration following USEPA procedures (Worcester et al., 1996). Turbidity was measured in the lab using a Hach

2100P Turbidimeter, which was calibrated according to the method described in the operating manual. Electrical conductivity was measured on unfiltered samples using YSI Model 3200 Conductivity Instrument with conductivity cell. Suspended sediment concentration was determined for each sample by gravimetric analysis using USEPA protocol for filtration, oven drying, and weighing based on precisely measured aliquots of each sample. The volume of the aliquot depended on the previously measured turbidity of that sample: the more turbid the sample, the smaller the aliquot. Sediment concentrations were calculated as milligrams of suspended sediment per liter. Quality control was evaluated by duplicate analyses every 10th and 20th sample out of every 24-sample set (Worcester et al., 1996).

Statistical Analyses of Event-Based Streamflow and Water Quality Data

Conceptually, an "event" occurs when streamflow exceeds the baseflow discharge, during and following sufficient rainfall. Criteria were used that classified observations into groups called "events." A computer program was developed to identify events with objectivity. The program, known as "*Stormfinder*" (David Paradies, Bay Foundation) delineated the beginning and end of an event according to slope of the rising limb of the hydrograph and the time elapsed since the end of the previous event. The hydrograph events were separated using the 30-minute streamflow data and identifying local flow minimums along single and multiple-peak hydrographs.

A paired dataset for statistical analysis purposes was derived using the hydrograph events defined by *Stormfinder*, and was combined with suspended sediment and turbidity data for each of the paired watersheds from the sampled storm events. The event-based dataset of turbidity, total suspended sediment, and streamflow was used for the statistical analysis. Water quality samples were taken at fixed 30-minute intervals during storm events occurring between January 1, 1995, and March 6, 2001. The 1993/94 and 2001/02 seasons were drought years, so dry that streamflow in Walters Creek was not sufficient for sample collection. Data were included in the dataset during any particular time interval only if the parameter of interest (sediment, turbidity, or flow) occurred for both streams - that is, was paired. There were times when instrument malfunction or operator error precluded successful collection of all parameters. All observations occurring before July 1, 1996 were considered to be pre-BMP, with all observations occurring since that date falling in the BMP period. This is referred to as post-BMP.

In 2001, close examination of the hydrographs revealed that in spite of several revisions, *Stormfinder* was delineating events that were not truly events - designating leading and trailing edges as storms, separately from the main hydrograph, for example. These are termed "false events," below. We closely examined 278 hydrographs representing sampling years from 1995 through March 2001, and eliminated a number of false events from the database, leaving 82 true paired events. The unedited dataset was archived. Statistical analyses were performed on the modified dataset of 82 storms.

The variable *Rain-yr* was used to implement streamflow and water quality data comparisons between years. *Rain-yr* 95 included events from January 1, 1995 to June 30, 1995. *Rain-yr* 1995-96 included events from July 1, 1995 to June 30, 1996. Subsequent rain years followed the July-through-June convention. Means of turbidity and suspended sediment for each event were calculated, data were log-transformed, then Walters was compared to Chumash by subtraction: dlogturb = $\log_{10}$(wturbmn) - $\log_{10}$(cturbmn) and dlogsed = $\log_{10}$(wsedmn) - $\log_{10}$(csedmn).

Descriptive statistics included number of observations (N), mean, median, trimmed mean (TrMean, calculated after removing the smallest five percent and largest five percent of the data; when there are fewer than 10 events, the mean and the trimmed mean will be identical), standard deviation, minimum and maximum, and first and third quartiles (Q1 and Q3), also known as the 25^{th} and 75^{th} percentiles.

To further quantify changes in water quality, several regression models were performed, all using dlogturb or dlogsed as the response, to evaluate whether reductions in suspended sediment export are detectable since BMP implementation began in 1996. Weighted least squares was used because the means were based on different numbers of observations. The number of observations used in the calculation of the mean is used as the weight for that mean (observation).

Two different predictor or independent variables were considered. The first predictor, Post BMP, was an indicator variable that equaled 0 if the observation was recorded prior to the start of BMP or 1 if the observation was recorded after the start of BMP. Using this variable in a regression function gives us a method of determining if (and by how much) the differences in the logs of the mean turbidity exiting the two watersheds changes after implementation of BMP practices. The second predictor, BMP Time, was used to better measure the possibility of slow but steady differences in turbidity between the watersheds. This variable was zero for observations at time periods before the start of BMP, but equaled the number of days after the start of BMP for any observations taken on or after July 1, 1996. For example if an event occurred on February 26, 1996, the value of BMP Time would be zero. If we had an event occurring on September 15, 1996, the value of BMP Time would be 77 (the 77^{th} day after BMP implementation began). This predictor variable allows us to model measures of water quality as a function of duration of BMP practices in the Chumash Creek riparian and upper watershed areas.

An alternative regression analysis was performed to evaluate the importance of time since BMPs were implemented. This also was a weighted analysis using the frequency of observations of each event as weights. This new model used five indicator variables, one for each rain year after the start of BMP. A regression equation modeling dlogturb versus indicators for 96-97, 97-98, 98-99, 99-00, 00-01 was used.

For each regression model attempted, a test for normality of errors was also performed. This test was the Ryan-Joiner test, which is similar to the Shapiro-Wilk test, and is based on calculating the correlation between the residuals for the model, and the expected values of the ordered residuals if the random error term was actually normally distributed. In the discussion that follows, if the test for normality was rejected at a significance level of .05 or less, the model is assumed to have failed the normality test. If the P-value associated with the normality test was greater than .05, the model was assumed to have passed the normality test.

A weighted analysis of variance was performed on turbidity and sediment data, comparing *dlogturb* over years (with pre BMP data combined into a "year"). This is equivalent to the regression analysis, except it allows us to compare data between any two years, rather than each year against only pre-BMP.

Statistical analyses of the event-based water quality data were conducted to answer the following questions:

a. Have the levels of turbidity for Chumash Creek compared to the turbidity for Walters Creek changed after BMP implementation on the Chumash Creek watershed? If levels have changed, what is the direction of change and is the magnitude of change statistically significant?

b. Have the levels of suspended sediment for Chumash Creek compared to suspended sediment for Walters Creek changed after BMP implementation on the Chumash Creek watershed? If levels have changed, what is the direction of change and is the magnitude of change statistically significant?

c. Has the relationship of flow for the Chumash Creek compared to the flow for Walters Creek changed after BMP implementation on the Chumash Creek watershed? If levels have changed, what is the direction of change and is the magnitude of change statistically significant?

d. What is the relationship between turbidity and suspended sediment for Chumash Creek before BMP implementation, and what is the relationship between turbidity and suspended sediment for Walters Creek before BMP implementation? In what way, if at all, do these relationships changed after BMP implementation?

Even-Interval Streamflow Monitoring

Regular interval flow sampling was conducted on a biweekly basis during the summer and on a weekly basis in the winter to coincide with water quality sampling. In 1996, a temporary V-notch weir was installed to measure low flow in the Chumash flume, but was discontinued. For the majority of the project duration, flow measurements were primarily taken using a gurley flow meter at Chumash and Walters Creeks by Regional Board staff and volunteer monitors. During storm events, flow was measured in the flume (as discussed previously).

Even-Interval Water Quality Monitoring

Weekly sampling began on Chumash and Walters Creeks in 1993 and was conducted for twenty weeks during winter and spring through 2001. Start and ending dates for storm season sampling did not coincide from year to year because sampling began with the first major runoff event. Bi-weekly sampling ensued through the rest of the year at Chumash Creek; Walters Creek was sampled until it became dry.

Water quality parameters including pH, conductivity, dissolved oxygen, and water temperature were measured using a hand held multi-functioning water quality meter. Grab samples were taken for total and fecal coliform bacteria, nitrate and phosphate, and were sent to the Regional Board contract laboratory (FGL Environmental, Creek Environmental, and BC Laboratories) for analysis. Turbidity was measured using a portable Hach Turbidimeter. Turbidity is a measurement of water clarity. The NTU value increases as the amount of light that can be transmitted through a sample decreases. It measures both organic and inorganic matter.

During the winter-spring sampling period, grab samples were also collected for total filterable solids. These samples are analyzed at the Cal Poly Soil Science Department Paired watershed Lab according to protocols established for storm-event sampling analysis. Sample collection, transfer, and holding time requirements follow the Quality Assurance Plan (Worcester, 1996).

Statistical Analyses of Even-Interval Streamflow and Water Quality Data

Basic statistical examination has included (1) evaluation of Chumash Creek and Walters Creek before and after BMP implementation, and (2) evaluation of the relationship of Chumash Creek to Walters Creek during both time periods. Rather than separately analyzing before and after BMP periods, a single regression model was developed using regression variables to indicate the creek and time period. Thus, the regression effectively allows testing the difference between creeks and additionally testing the difference of differences (i.e. the effect of BMP – the comparison of most interest) (Table 3.2). In this regression, the difference of differences would truly be a result of BMP implementation and not natural differences in stream parameter response to the environment. Two types of repeated measures regression models recommended and designed specifically for this study by Smith and Wright (2000) were used to examine the data. The actual regression model parameterization estimates the overall average difference between creeks and then estimates an additional difference due to implementation of BMP.

Table 3.2. Graphical depiction of a repeated measures regression model using water temperature data from Chumash and Walters Creeks.
Differences in pre-BMPs are calculated into the post-BMP statistical analysis along with an error term for the autocorrelation caused by the weekly sampling scheme.

<table>
<tr><td>Pre-BMPs

Walters water temperature μ=18.02°C</td><td>Post-BMPs

Walters water temperature μ=18.02°C</td></tr>
<tr><td>Chumash water temperature μ=17.15°C</td><td rowspan="2">Additional Δ°C=1.37

Chumash water temperature μ=15.73°C</td></tr>
<tr><td rowspan="2">Δ°C=0.87

P=0.0175*</td></tr>
<tr><td>P=0.0029**</td></tr>
</table>

*α=0.05 **α=0.01

Five parameters were explored using repeated measures regression models to analyze the paired water quality data before and after implementation of BMPs for Chumash Creek and Walters Creek. The parameters consisted of physical, chemical, and biological components and included water temperature, dissolved oxygen, turbidity, nitrates, and fecal and total coliform bacteria. Two regression models were used:

1. A repeated measures linear regression $y = \mu$ + effects creek + effect BMP + $\varepsilon_{date} + \varepsilon_{random}$ and
2. A repeated measures binary logistic regression, logit P (y>threshold) = μ + effects creek + effect BMP + $\varepsilon_{date} + \varepsilon_{random}$.

A repeated measures linear regression differs from an ordinary linear regression by incorporation of an additional 'error' term. In this analysis the residual error can be considered primarily due to assay variability, while the date error can be considered due to temporal variation (e.g. weather). As such, the temporal variation is allowed to be correlated (i.e. date errors a week apart are more similar than date errors a few months apart). Likewise, a repeated measures logistic regression differs from an ordinary logistic regression only by the additional variability term for temporal variation.

The linear regression model simultaneously determines the difference between creeks and any additional difference due to implementing BMPs. The repeated measures linear regression model is used for all normally distributed data. Water temperature and dissolved oxygen have variability not dependent on the parameter level (e.g. variability is about the same at low water temperatures and high water temperatures).

The parameters fecal coliform, nitrate, and turbidity, are not normally distributed (i.e. the majority of the data does not fall near the average) and exhibit increasing variability at increasing levels.). Thus, each of these parameters was analyzed using a binary logistic regression model. To create a binary outcome for each parameter, a threshold value indicative of water quality objectives or the median of the complete data set was selected. The methods NMP project staff used to select threshold values are discussed further below. Each value lower than the threshold received a 0 and each value above the threshold received a 1. After the data were assigned a binary number, the logistic regression model predicted the logit probability of exceeding the threshold as a function of the creek and BMPs. The repeated measures logistic regression also allowed for temporal and residual variation.

NMP project staff used two threshold values, based on the Regional Water Quality Control Board's Basin Plan (1994), to analyze fecal coliform bacteria. The first value (200 Most Probable Number (MPN)/100 mL) is the water quality objective for Water Contact Recreation (REC-1) . The second threshold value (2000 MPN/100 mL), is the water quality objective for Non-Contact Water Recreation (REC-2). Two thresholds were selected in order to analyze fecal coliform bacteria both during high level storm events and during base flow conditions.

NMP project staff also analyzed turbidity and nitrogen using established threshold values. Two turbidity threshold values were selected. The first (7 NTUs), is based on the median of the data set, and the second (50 NTUs)s is based on recommended salmonoid requirement levels by G.W. Harvey (1989), in EPA's Monitoring Protocols to Evaluate Water Quality Effects of Grazing

Management on Western Rangeland Streams. NMP project staff also analyzed nitrate as nitrogen and orthophosphate as phosphate using the median of the data sets (0.700 mg/L and 0.015 mg/L, respectively). These threshold values are on average less than the Central Coast Ambient Monitoring Program (CCAMP) attention levels (K.Worcester, personal communication, 2002). The objectives of BMP implementation at Chumash Creek using data collected on a weekly even interval were:

a. Lowering water temperature in the Chumash Creek in comparison to Walters Creek

b. Maintaining healthy levels of dissolved oxygen in the Chumash Creek

c. Lowering nitrate-nitrogen levels in the Chumash Creek in comparison to Walters Creek Lowering turbidity levels in the Chumash Creek in comparison to Walters Creek

d. Lowering fecal coliform bacteria levels in the Chumash Creek in comparison to Walters Creek

3.2.3 Rapid Bioassessment

Following State of California protocols for Rapid Bioassessment, adapted from the EPA methodology (Plafkin et al., 1989), Rapid Bioassessment was conducted throughout the Morro Bay watershed in 1994, 1995, 1996, 1997, 1999, and 2001. Rapid bioassessment began at Chumash Creek and Walters Creek in 1996. As seasonality is a concern with macroinvertebrate sampling, all Rapid Bioassessment sampling occurs within a month's period during the late spring, consisting of both Benthic Macroinvertebrate Analysis and Habitat Assessment. Benthic macroinvertebrate samples have been processed for species composition for 1994, 1995, 1996, 1997, and 1999 by the California Department of Fish & Game. Samples from 2001 are being analyzed and will be incorporated into the analysis in the Final Report.

Benthic invertebrate sampling is a useful biosurvey technique for water quality assessment. The biological community can reflect overall ecological integrity and provide data concerning the pollutant stressors placed on a stream ecosystem (Plafkin et al., 1989). Macroinvertebrates are advantageous as a sampling target due to their propensity to indicate local conditions and environmental changes, their abundance as a sampling target, and the relative ease of sampling. Additionally, macroinvertebrate communities tend to reflect environmental conditions on a smaller scale compared to fish due to their high diversity and smaller habitat range.

Metrics have been developed in order to "grade" benthic invertebrate diversity. Impairment of the biological system may exhibit itself by the absence or reduction of generally pollution-sensitive macroinvertebrates such as Ephemeroptera, Plecoptera and Trichoptera; dominance by a singular taxon (especially tolerant species); absence of expected species; or significant shifts in the composition compared to a reference site. Below is a description of some metrics, which are commonly used in benthic macroinvertebrate analysis. Some of these metrics have been applied in the analysis.

Richness measures reflect the health of the community through a measurement of the variety of taxa present. Taxonomic richness measures the overall variety of the macroinvertebrate

assemblage. EPT taxa is the number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).
Composition measures indicate compositional values of the community. EPT index percent is the percent of the composite of Ephemeroptera, Plecoptera and Trichoptera larvae. Shannon diversity index incorporates both richness and evenness in a measure of general diversity and composition.
Tolerance/intolerance measures indicate values pertaining to taxa groups, which are divided by their tolerance or intolerance to differing levels of water quality pollutants. Percent dominant taxon measures the dominance of the single most abundant taxon.
Trophic measures reflect abundance of invertebrates in specified trophic levels. The percentage of collectors, grazers, shredders, predators, and filterers describe the distribution of invertebrates in a particular trophic group as a percentage of the entire sample.
Index of Biological Integrity combines several metrices to provide a more comprehensive analysis.
Indices are combinations of metrics that have been compiled and utilized to better reflect water quality.

3.2.4 Rangeland Vegetative Monitoring

Vegetation transect monitoring was conducted to document field changes over time through plant composition and biomass. Vegetation monitoring included identification of species composition, total dry matter (biomass), and percent cover (standing vegetation, persistent litter, nonpersistent litter, and bare ground). Four permanent and representative sampling transects were located in each watershed. Transects were chosen based on slope, aspect, soils, and vegetation, and each transect in Chumash was paired with a similar transect in Walters: RC1 in Chumash was paired with RW1 in Walters, RC2 with RW2, and so on. The 100 point-step method was used along each transect during late fall and late spring to document ground cover, plant growth, plant form, and diversity (U.S. Department of the Interior, Bureau of Land Management, 1984).

During fall sampling, the condition of vegetation did not allow for identification of species, but plants were identified as either grasses or forbs. In spring, plant species were identified to genus and species. During both spring and fall, vegetation (also referred to as foliar cover) and nonfoliar cover were quantified. Nonfoliar cover consisted of bare ground, persistent litter, and nonpersistent litter. Both persistent and nonpersistent litter were considered to be in the fraction within one-half inch depth on the soil surface. Each species or form of vegetation, persistent litter, nonpersistent litter, and bare ground were calculated and are reported as percents of the total ground cover.

Bare ground consisted of exposed soil surface and included dirt roads, cattle trails, and gopher and ground squirrel spoil. Persistent litter was identified as organic matter that persists on the soil surface for more than one year. Persistent litter includes animal manure and woody vegetation. Nonpersistent litter was identified as the organic matter that accumulates on the soil surface but is decomposed within a year.

Biomass (dry mass) was sampled by random tossing of a square (1 square foot in area) 5 to 8 times per transect (depending on transect length and topography). All vegetation contained within the square was clipped and collected. Clipped samples were transported to the laboratory, oven dried, and weighed. Biomass was recorded as grams per square foot, and pounds per acre were calculated (U.S. Department of Agriculture, NRCS, 1997). After determination of biomass, the oven dried samples were saved for forage quality measurement (described below).

Data were analyzed using regression analysis. The characteristics biomass, average plant height, vegetative density, and percents bare ground, nonpersistent litter, grasses, forbs, purple needlegrass (a desirable species), thistle (an undesirable species), and number of species (as an assessment of diversity) were response variables. For the regression analysis, the response variables were calculated as the difference (Chumash - Walters) between each, for each transect pair, for example, Biomass_{RC1} - Biomass_{RW1}. Treatment (pre- versus post-BMP implementation) served as the main predictor variable. In separate analyses, rainfall, forage consumption per acre, and consumption divided by the square root of time since the pasture was grazed were covariables with treatment. Spring and Fall data were analyzed separately. The number of observations consisted of years pre-BMP (Fall: 2, Spring: 3) + years post-BMP (Fall: 6, Spring: 6), with July 1, 1996 taken as the date of BMP implementation. In all analyses, results were considered to be significant at P values ≤ 0.05.

This parameter is equal to biomass in grams per square foot, divided by plant height in feet. It was designed to compensate for the partial removal of vegetation by grazing, in that height and biomass would be removed proportionately, and allow for comparisons between grazed and ungrazed pastures.

Regression analysis was chosen because of the small number of observations. Forage consumption and time since grazing were used as covariables, since it was evident that, particularly in the Chumash watershed, data would be different depending on if sampling had been performed before or after the pasture had been grazed. Forage consumption was standardized with respect to the amount of each pasture allocated to each transect. The square root of time since latest grazing was chosen because the rate of growth of plants is not linear with time, and trial-and-error showed that the square root function yielded the best statistical results.

The small number of observations (3 years of pre-BMP data at best) precluded statistical analysis of pre- and post-BMP comparisons in the Chumash watershed. Geographical Information Systems technology was applied to track before vs. after changes in Chumash, on a pasture-by-pasture basis.

3.2.5 Stream Channel Profiles

Four permanent paired reaches on each of Walters and Chumash creeks were characterized, in late fall and late spring. The reaches were paired between watersheds, based on similarities in shape, vegetative composition, width, total drainage area, type of stream, stream order, branching, and position. The reaches ranged from 70 to 100 feet in length, depending on the uniformity of each channel. Within each reach, three cross-sectional stream profiles were recorded using an automatic level and Philadelphia rod.

3.2.6 Channel Stability Evaluations

Pfankuch channel stability evaluations were conducted on each of the permanent reaches throughout the monitoring period. The Pfankuch method is a visual assessment of the stream based on factors such as bank vegetative composition, bank rock content, and stream width to depth ratio (Pfankuch, 1978). With this system, low numbers are indicative of a more stable stream system and are desirable, while high numbers are indicative of an unstable stream system.

3.2.7 Geographical Information System

A geographical information system (GIS) was developed for the Paired Watershed project to map features and to evaluate spatial characteristics of the Paired Watershed for non-point pollution sources. The GIS mapped features with relationships to rangeland and soil erosion. The evaluations focused on the erosion potential of the rangeland and the possible reduction in erosion because of the implementation of Best Management Practices (BMPs).

3.2.8 Forage Quality

Beginning about 1992, Cal Poly's Animal Science Department noticed that supplemental feed costs per cow were decreasing (Fig. 3.39). Lower costs per cow thus began before the project was initiated, so while not a result of BMPs, we hypothesized that BMPs might lead to improvements in range quality, according to this model: more vegetation and nonpersistent litter → more organic matter and nutrients cycled into the soil → improved soil quality → improved range quality. Thus, based on an outcome not directly related to the project, we established testing of this hypothesis to be a new or secondary objective. In 1999, Project Staff sought and received funding through an Agricultural Research Initiative (ARI) grant, administered by the California State University, to continue data collection and to add a new subtask, range quality monitoring. Crude protein (as an indication of protein content in the plant) and neutral- and acid-detergent fiber (NDF and ADF) fractions were measured on samples collected for range productivity determinations.

The amount of nutrient availability to the grazing animal is a function of mass of the vegetation, the nutrient content, and the availability to the animal. In order to adequately determine the amount of energy and protein (the two most common limiting nutrients in grazing animals), it is necessary to test the forage for carbohydrate (for energy) and protein. The product of vegetation mass and nutrient composition is an estimate of energy and protein contained within the forage. The most common estimate of energy is to measure the acid detergent fiber and neutral detergent fiber, and estimate net energy for maintenance, growth, pregnancy, lactation and so on using previously described and validated empirical equations. Once the net energy is calculated, it becomes a simple matter to perform a nutrient balance on the cattle and range, thereby more closely matching the nutrient availability with the needs of the animal.

Vegetation samples from spring and fall sampling had been dried and stockpiled in the laboratory, since 1995. Samples collected and stored since 1998 were ground and tested for acid detergent and neutral detergent fiber. The year 1998 was selected as being sufficiently past the date of BMP implementation to have begun showing progressive improvement, if any improvement were present. After sample retrieval in the field, the bagged grasses were dried in the oven at 85 degrees Celsius for 24 hours. Samples were boxed or bagged for storage until testing could begin. Collected grass samples were ground in a Wiley Mill through a 2-millimeter screen. Each transect area (RW1, RC1, etc.) was represented by 6 to 9 samples. Portions of each transect were combined to create one larger sample for each transect area (RW1-RW4 Spring and Fall : RC1-RC4 Spring and Fall), for a total of 16 samples per year. Approx. 1 gram (±0.05 g) from each original sample was weighed on the analytical scale and to give a final composite sample for testing of 6-9 grams. The combined sample was processed in a Tecator 1093 micro-grinder sample mill equipped with a 1-mm screen, collected and stored for dry matter analysis and determination of neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin.

Dry matter was determined using a moisture analyzer (Ohaus MB45; 100 C, 10 min timed test) with 1 gram of sample.

All ADF and NDF fiber analyses were conducted using an Ankom Technology Fiber Digester with nylon bags. The procedures were followed as described by Ankom, and supplies were purchased from Ankom Technologies. Samples were approximately 0.5g, sealed in individual bags, 24 bags per digestion in 2000 ml digestion solution. Calculation of NDF

Calculate percent aNDF (as-is basis) = $\underline{(W_3 - (W_l \times CJ) \times 100\ W_2}$

aNDF (DM basis): $\underline{(W_3 - (W_l \times C_l)) \times 100\ W_2 X\ DM}$

$aNDF_{OM}$(DM basis): = $\underline{(W_4 - (W_l \times Cv) \times 100\ W_2 x DM}$

Where:

W_1 = Bag tare weight
W_2 = Sample weight
W_3 = Weight after extraction process
W_4 = Weight of Organic Matter (OM) (loss of weight on ignition of bag and fiber residue)
C_l = Blank bag correction (final oven-dried weight/original blank bag weight)
C_2 = Ash corrected blank bag (loss of weight on ignition of blank bag/original blank bag weight)

Calculation of ADF

Calculate percent ADF (as-is basis): = $\underline{(W_3 - (W_l \times C_l)) \times 100\ W_2}$

ADF (DM basis): = $\underline{(W_3 - (W_l \times C_l)) \times 100\ W_2 \times DM}$

$$ADF_{OM}(DMbasis): = \frac{(W_4-(W_l \times C_2))x100}{W_2 \times DM}$$

Where:

W_1 = Bag tare weight
W_2 = Sample weight
W_3 = Weight after extraction process
W_4 = Weight of Organic Matter (OM) (Loss of weight on ignition of bag and fiber residue)
C_l = Blank bag correction (final oven-dried weight/original blank bag weight)
C_2 = Ash corrected blank bag (Loss of weight on ignition of bag/original blank bag)

Calculation of Lignin

Calculate percent ADL (as-is basis): $= (W_3 - (W_1 \times C_1)) \times 100\ \underline{W_2}$

ADL (DM basis): $= \underline{(W_3 - (W_1 \times C_1)) \times 100\ W_2 \times DM}$

ADLOM (DM basis): $= \dfrac{(W_4 - (W_1 \times C_2)) \times 100}{W_2 \times DM}$

Where:

- W_1 = Bag tare weight
- W_2 = Sample weight
- W_3 = Weight after extraction process
- W_4 = Weight of Organic Matter (OM) (Loss of weight on ignition of bag and fiber residue)
- C_1 = Blank bag correction (final oven-dried weight/original blank bag weight)
- C_2 = Ash corrected blank bag (Loss of weight on ignition of bag/original blank bag)

Statistical Analyses

The ANOVA model for all variables was:

$$Y_{ijkl} = \mu + R_i + S_j + T_k + RST_{ijk} + \varepsilon_{ijkl}$$

where Y_{ijkl} was the observation (percent moisture, percent ADF, percent NDF or percent lignin) for the k-th treatment of the j-th season during the i-th year, where i = 1998, 1999, or 2000; l = 1,2; j = fall or spring; and k = treatment or control. T_k was the k-th treatment effect (a fixed effect), S_j was the j-th season effect (a fixed effect), R_i was the year effect (a fixed effect), and ε_{ijkl} was the residual error due to the (i, j, k)-th observation assumed to be randomly normally distributed with mean 0 and variance σ^2, where σ^2 was estimated by the ANOVA mean square error.

3.3 Results and Discussion

3.3.1 Climate, Streamflow, and Event-Based Monitoring

The study period included years with both above and below average rainfall Measurable rainfall usually occurs during the fall and winter months, however, depending on rainfall amounts, distribution, and intensity, measurable responses in streamflow often were not observed until around January.

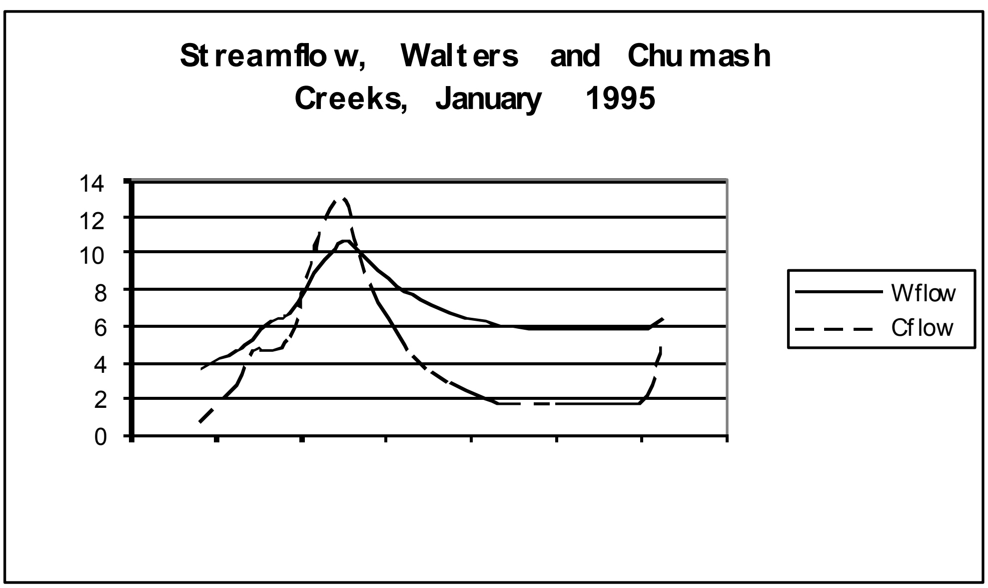
Streamflow for the paired watersheds has been highly dependent on rainfall intensity and distribution, and seems also dependent on antecedent soil moisture (not measured), timing of storms, and the geometry of the watersheds. Descriptive statistics of streamflow for Walters and Chumash Creeks show no apparent systematic trends related to BMPs. At least some of this may be related to unaccounted variations in climate, differences in geometry and substrate between the two watersheds, and to mechanical breakdowns, software deficiencies, and operator errors resulting in lost streamflow data. Loss of streamflow data precluded calculation of sediment loads. The significance of this is discussed below in Conclusions, and in Chapter 9.

Table 3.3. Descriptive statistics of event-based streamflow of Walters (wflowall) and Chumash (cflowall), by Rain-yr.

Variable	Rain-yr	N	Mean	Median	TrMean	StDev	SE Mean	Minimum	Maximum	Q1	Q3
wflowall	95	13	33.11	21.28	31.22	25.71	7.13	6.99	80.01	15.93	56.21
	95-96	2	7.675	7.675	7.675	0.399	0.282	7.393	7.958	*	*
	96-97	11	27.74	30.35	27.30	18.09	5.45	0.54	58.90	13.46	42.01
	97-98	5	18.10	19.16	18.10	7.34	3.28	8.85	25.05	10.63	25.04
	98-99	2	7.696	7.696	7.696	1.376	0.973	6.723	8.669	*	*
	99-00	9	20.65	20.48	20.65	10.63	3.54	5.27	41.25	13.58	26.49
	00-01	13	9.85	10.67	9.54	3.68	1.02	5.61	17.44	6.46	12.23

Variable	Rain-yr	N	Mean	Median	TrMean	StDev	SE Mean	Minimum	Maximum	Q1	Q3
cflowall	95	13	17.89	12.66	17.14	13.49	3.74	2.68	41.26	7.46	32.59
	95-96	2	17.25	17.25	17.25	4.83	3.42	13.84	20.67	*	*
	96-97	11	28.62	28.94	28.19	13.44	4.05	5.01	56.14	19.30	37.22
	97-98	5	29.23	31.14	29.23	6.59	2.95	19.58	37.11	23.00	34.50
	98-99	2	12.49	12.49	12.49	6.81	4.82	7.67	17.30	*	*
	99-00	9	20.84	20.88	20.84	11.17	3.72	5.23	42.27	12.21	28.03
	00-01	13	9.16	8.63	8.69	6.18	1.72	1.67	21.80	3.82	14.34

Examination of paired hydrographs from 1995 through 2001 revealed interesting trends. In the period of 1995 through 1998, the timing of peak flow in Walters and Chumash was approximately equal. Beginning early in 1999, peak flow of Chumash lagged behind that of Walters, by 30 minutes to 1 hour (Fig. 3.5). This was most noticeable early in the seasons. We hypothesize this is due to increased interception of water by plants, and increased infiltration in the Chumash watershed, as vegetation increased on streambanks and in the watershed. Later in each year, hydrographs of Chumash more closely match Walters, perhaps attributable to saturation of soils in the Creek, and greater responsiveness of streamflow to rainfall.



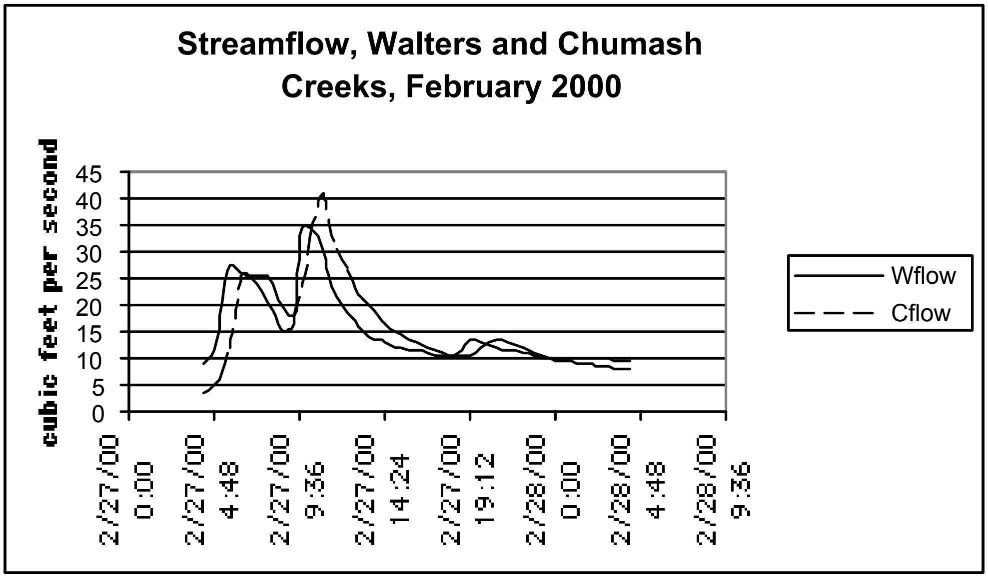


Figure 3.5. Hydrographs of Walters and Chumash Creeks, before BMP implementation (upper) and approximately 3.5 years following BMP implementation (lower).

3.3.2 Event-Based Water Quality

As of the 2000-01 season*,* the complete data set contained 82 events that included paired data on turbidity, and 80 events that included paired data on sediment. Descriptive statistics (Table 3.4) show that water quality has improved in Chumash relative to Walters, but that improvement has leveled off, or plateued, beginning with the 1999-2000 sampling season (Table 3.4; Figures 3.6 and 3.7).

Table 3.4. Descriptive Statistics: dlogturb by Rain-yr (upper) and dlogsed by Rain-yr (lower).

Turbidity

Variable	Rain-yr	N	Mean	Median	TrMean	StDev	SE Mean	Minimum	Maximum	Q1	Q3
dlogturb	1995	15	-0.3477	-0.3827	-0.3551	0.2933	0.0757	-0.7946	0.1943	-0.5645	-0.1075
	1995-96	4	0.010	0.061	0.010	0.243	0.122	-0.327	0.247	-0.238	0.209
	1996-97	12	-0.0833	-0.1340	-0.1070	0.2346	0.0677	-0.4163	0.4875	-0.2173	-0.0312
	1997-98	25	0.0067	0.0043	0.0087	0.1814	0.0363	-0.4259	0.3913	-0.0992	0.1159
	1998-99	3	0.498	0.418	0.498	0.240	0.138	0.308	0.767	0.308	0.767
	1999-00	9	0.447	0.413	0.447	0.318	0.106	-0.051	0.976	0.220	0.724
	2000-01	14	0.3761	0.3568	0.3659	0.2871	0.0767	-0.1016	0.9760	0.1837	0.5578

Sediment

Variable	Rain-yr	N	Mean	Median	TrMean	StDev	SE Mean	Minimum	Maximum	Q1	Q3
dlogsed	1995	14	-0.2669	-0.3240	-0.2804	0.3732	0.0998	-0.8234	0.4515	-0.5398	-0.0343
	1995-96	4	-0.020	0.012	-0.020	0.213	0.106	-0.298	0.193	-0.239	0.167
	1996-97	12	0.0013	-0.0340	-0.0289	0.2790	0.0805	-0.3266	0.6306	-0.2517	0.1970
	1997-98	25	-0.0360	-0.0234	-0.0303	0.2150	0.0430	-0.5436	0.3414	-0.1680	0.0941
	1998-99	3	0.339	0.212	0.339	0.221	0.127	0.212	0.594	0.212	0.594
	1999-00	9	0.6047	0.5667	0.6047	0.2945	0.0982	0.2549	1.1047	0.3454	0.8428
	2000-01	13	0.310	0.171	0.270	0.362	0.100	-0.117	1.175	0.035	0.551

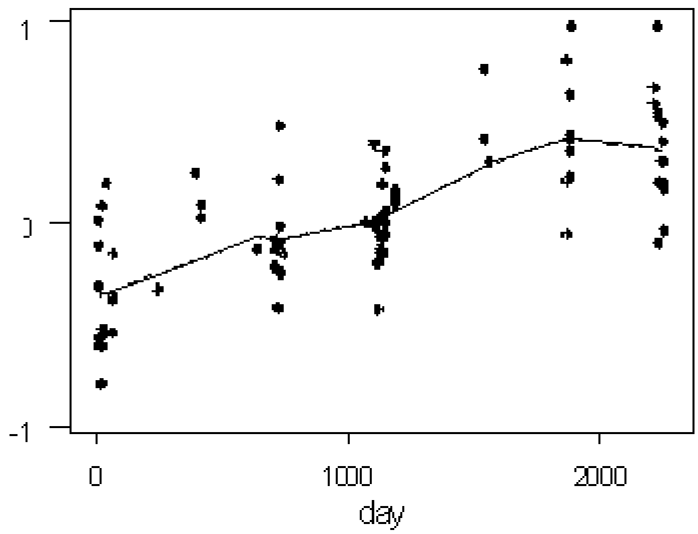


Figure 3.6. Graph of <u>*dlogturb*</u> = $\log_{10}$(<u>*wturbmn*</u>) - $\log_{10}$(<u>*cturbmn*</u>), with LOWESS line superimposed.

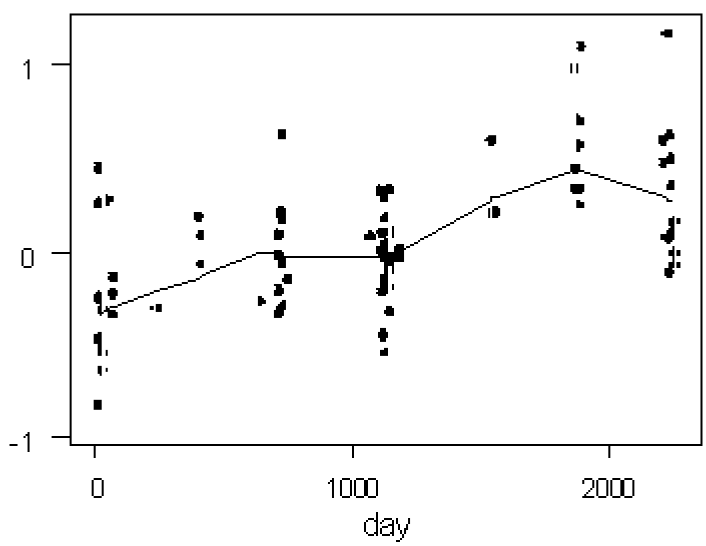


Figure 3.7. Graph of <u>*dlogsed*</u> = $\log_{10}$(<u>*wsedmn*</u>) - $\log_{10}$(<u>*csedmn*</u>), with LOWESS line superimposed.

In Fig. 3.6 and 3.7, the first two clusters of points on the left side of each graph are before BMP implementation began, while the five clusters toward the right are events that occurred after the initiation of BMP. The plateau indicates that BMPs had an effect that took 2 to 3 years to mature. This possibility is discussed later.

Regression Model—Post BMP, Turbidity and Sediment

Means of turbidity and sediment were analyzed, and are displayed graphically, using two initial treatments. In the first treatment, *dlogturb* (or *dlogsed*) was plotted versus pre-BMP or post-BMP. The second treatment plots *dlogturb* (*dlogsed*) versus time since monitoring began. In this latter treatment, the x-axis variable *day* is the number of days since January 1, 1995. The y-axis variable (dependent variable or response) is *dlogtur*b or *dlogsed*. Each observation therefore represents the value of *dlogturb* (or *dlogsed*) for an event occurring at a given number of days after January 1, 1995. The second treatment plots the same event data with a LOWESS regression line superimposed on each. The LOWESS line is a "*LO*cally *WE*ighted *S*catterplot *S*moother," which does not depend on a specific model and serves as a guide as to whether or not there is a systematic pattern in the relationship between the two variables.

Using Post-BMP as the predictor and *dlogturb* and *dlogsed* as the response variables, the analysis indicates that if the model assumptions are satisfied, there is a significant difference in each water quality parameter, between pre- and post-BMP (Table 3.5). In the analysis of turbidity, the test for normality yielded a p-value = 0.037, indicating a mild deviation from normality, and the residuals have a slight skew to the right. In the analysis of sediment, the test for normality yielded a p-value = 0.0426, also indicating a mild deviation from normality, and the residuals have a slight skew to the right.

Table 3.5. Results of regression analysis, dlogturb versus post-BMP, and dlogsed versus post-BMP.

Response Variable	Regression Equation	R^2
dlogturb	dlogturb = -0.230 + 0.377(post-BMP)	21.9%
dlogsed	dlogsed = -0.186 + 0.342(post-BMP)	14.5%

Regression Model—BMP Time, Turbidity and Sediment

In the analysis using *BMP Time* as the predictor and *dlogturb* (or *dlogsed*) as the response in a weighted regression analysis, the interpretation is that water quality parameters in Chumash have shown a slight but steady improvement with time following BMP implementation (Fig. 3.8 and 3.9). Values of R^2 are substantially higher than in the Post-BMP analysis (compare Table 3.3 with Tables 3.4 and 3.5), and the natural conclusion is that BMP Time allows a more reliable relationship of water quality to BMP implementation. However, caution should be taken in interpreting the calculated values of R^2 since the use of weighted regression invalidates its usual interpretation. The calculated values can be used to provide a general indication of the explanatory abilities of our various regression models. In both analyses, the tests for normality yielded p-values > 0.10; thus, there is no significant evidence of a problem with normality.

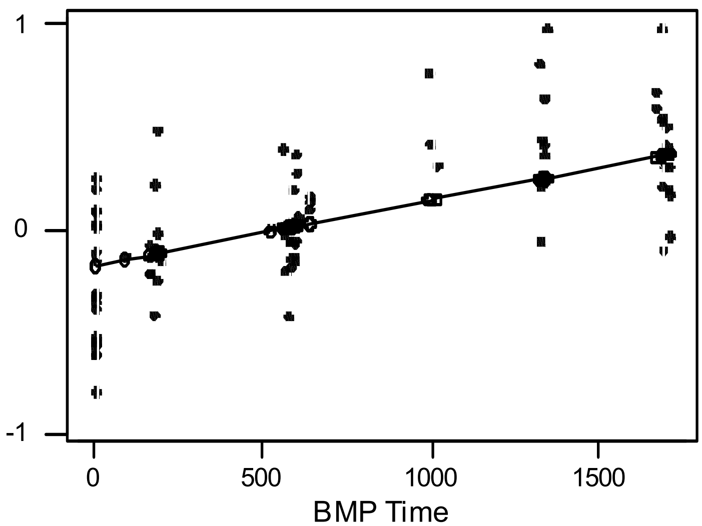


Figure 3.8. Regression analysis of BMP Time (days since monitoring began) with dlogturb as the response variable, and LOWESS line superimposed. R^2 = 39%.

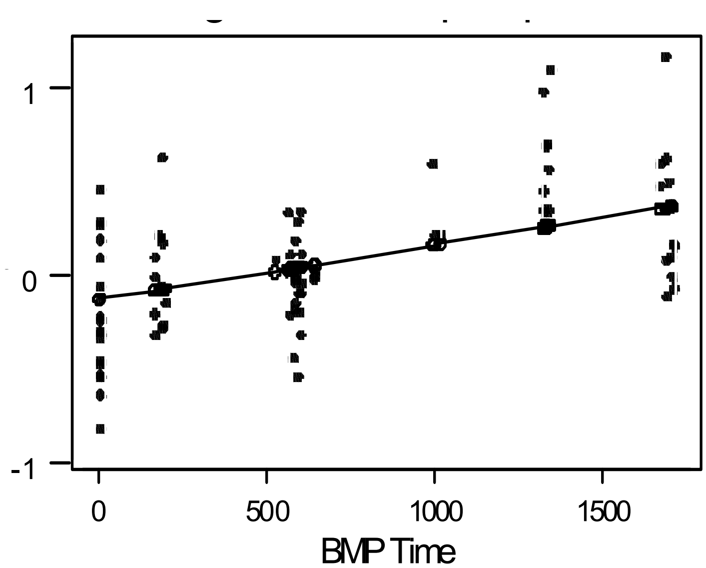


Figure 3.9. Regression analysis of BMP Time (days since monitoring began) with dlogsed as the response variable, and LOWESS line superimposed. R^2 = 26.3%.

In the *dlogturb* dataset, while normality seemed satisfied, two points were marked as outliers. Removing first the largest outlier, then the second outlier, yielded higher values of R^2 compared to the treatments with no outliers removed (Table 3.6). Likewise, in the dlogsed analysis, normality was satisfied, but two points were marked as outliers. Removal of these two outliers yielded a higher value for R^2 (Table 3.7).

Table 3.6. Summary of the regression models, with and without outliers, dlogturb as the response variable and BMP Time as the independent variable.

Number of observations deleted	Estimated Regression line	R^2	t-value for slope	P-value for t-test	Normality test result
None	-0.176+0.000316x	39.0%	7.14	0.000	Pass (P>.10)
One	-0.192+0.000372x	49.1%	8.73	0.000	Pass (P>.10)
Two	-0.223+0.000393x	55.9%	9.94	0.000	Pass (P>.10)

Table 3.7. Summary of the regression models, with and without outliers, dlogsed as the response variable and BMP Time as the independent variable.

Number of observations deleted	Estimated Regression line	R^2	t-value for slope	P-value for t-test	Normality test result
None	-0.136+0.000293x	26.3%	5.28	0.000	Pass (P>.10)
Two	-0.192+0.000377x	41.3%	7.31	0.000	Pass (P>.10)

Caution should be used in interpreting the calculated values of R^2, since the use of weighted regression invalidates its usual interpretation. The calculated values can be used to provide a general indication of the explanatory abilities of our various regression models. The elimination of observations as outliers should also be practiced with caution, in studies where observations are sparse, due to mechanical difficulties, operator error, and the vagaries of nature.

Regression Model Using Rain Year as Indicator Variables

A regression analysis was performed, using estimated regression functions with five "slope" terms, one for each of the post-BMP rain years. This new model used five indicator variables, one for each rain year after the start of BMP. A regression equation modeling *dlogturb* versus indicators for 96-97, 97-98, 98-99, 99-00, 00-01 was generated for each of the response variables *dlogturb* and *dlogsed* (Table 3.8). If an event occurred prior to July 1, 1996 (the start of BMP), the value of each of the indicator variables is zero. For any event in a post-BMP year, the value of the indicator corresponding to the rain year for the event will be one, and the other indicator variables will have values of zero. Using this model, the "slopes" for the indicator variables are the mean difference of *dlogturb* or *dlogsed* for the year in question compared to the pre-BMP study time period. Essentially, the variables are measuring the improvement (in terms of *dlogturb* or *dlogsed*) in Chumash compared to Walters for that rain year compared to pre-BMP. In the turbidity analysis, slope changes with each rain year (Table 3.8), and supports our hypothesis that improvement in turbidity has reached a plateau, beginning in the 1999-2000 rain year. In the suspended sediment analysis, slope also changes each year, in a more erratic pattern. This regression model passed the test for normality.

Table 3.8. Regression equations using rain year following BMP implementation as the indicator variables, and dlogturb and dlogsed as response variables.

Regression equation	R^2
dlogturb = - 0.230 + 0.170 (97) + 0.232 (98) + 0.640 (99) + 0.561 (00) + 0.535 (01)	42.9%
dlogsed = - 0.186 + 0.219 (97) + 0.136 (98) + 0.446 (99) + 0.720 (00) + 0.436 (01)	39.3%

Analysis of Variance

The regression analyses confirmed the hypothesis that in the past two years, improvements in turbidity plateaued. Sediment did not appear to plateau. The hypothesis was tested using weighted analysis of variance. The analysis of variance uses indicator variables to compare post-BMP rain years to pre-BMP, including pairwise comparisons of means using Tukey's method (sometimes called Tukey's "Honestly Significant Difference" or HSD method).

The phrase "pairwise comparisons" describes the process of comparing every two means and determining if there is a significant difference between each of these pairs. Tukey's method makes these pairwise comparisons using what is known as a family or experimentwise level of significance. The basic idea is that these pairwise comparisons of means are made so that there is only an α chance (say .05) of any type I error (saying two means are different when they are equal) occurring over the complete set of comparisons. That is, there is a probability equaling α that <u>any</u> type I error will be made for the complete family of comparisons. Thus, we can be exceedingly confident in a decision that two means are significantly different. The procedure is conservative; thus, it increases the chance that we will not declare two means significantly different when they truly are unequal (a type II error). So, Tukey's procedure is less powerful than its less conservative alternatives; thus, in addition to the Tukey's procedure results, we have added ordinary p-values based on the usual Student's t-distribution (equivalent to Fisher's "Least Significant Difference" or LSD method) (Table 3.9; Fig. 3.10). Consider small p-values with this criterion to be indicative (rather than conclusive) of significant differences

Table 3.9. Summary of statistics of analysis of variance, dlogturb versus BMP Year.

Comparison	Difference	Standard Error	t-Value	Tukey p-value	Student's t p-value
(96-97) – Pre BMP	0.1698	0.09706	1.750	0.5040	0.0842
(97-98) – Pre BMP	0.2322	0.08454	2.747	0.0778	0.0075
(98-99) – Pre BMP	0.6398	0.19423	3.294	0.0181	0.0015
(99-00) – Pre BMP	0.5614	0.10307	5.446	0.0000	0.0000
(00-01) – Pre BMP	0.5355	0.08563	6.253	0.0000	0.0000
(97-98) – (96-97)	0.06241	0.09474	0.6587	0.9858	0.5121
(98-99) – (96-97)	0.47001	0.19888	2.3633	0.1825	0.0207
(99-00) – (96-97)	0.39153	0.11160	3.5085	0.0096	0.0008
(00-01) – (96-97)	0.36564	0.09572	3.8200	0.0036	0.0003
(98-99) – (97-98)	0.4076	0.19308	2.111	0.2928	0.0381
(99-00) – (97-98)	0.3291	0.10089	3.262	0.0199	0.0017
(00-01) – (97-98)	0.3032	0.08299	3.654	0.0061	0.0005
(99-00) – (98-99)	-0.0785	0.2019	-0.3887	0.9988	0.6986
(00-01) – (98-99)	-0.1044	0.1936	-0.5392	0.9943	0.5913
(00-01) – (99-00)	-0.02589	0.1018	-0.2543	0.9998	0.8000

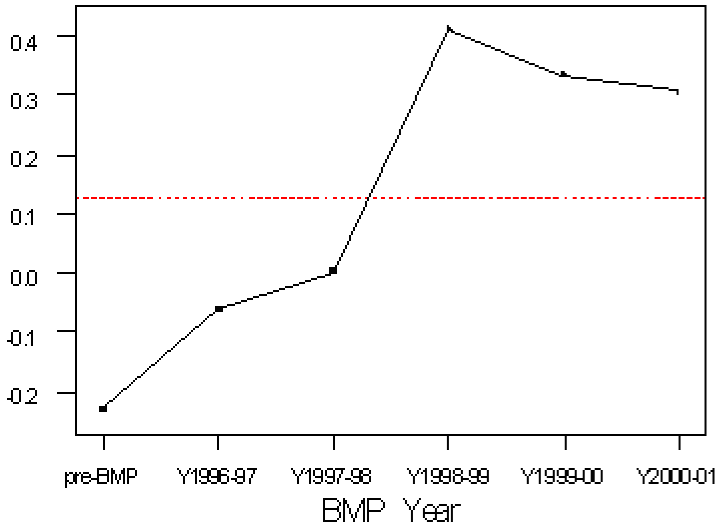


Figure 3.10. Graph of the turbidity means being compared by analysis of variance.

From the table and graph, we can conclude, at α = .05 (experimentwise for Tukey, individually for Student's t):

Tukey:

1998-1999, 1999-2000, and 2000-2001 are significantly greater than Pre BMP
1999-2000, and 2000-2001 are significantly greater than 1996-1997
1999-2000, and 2000-2001 are significantly greater than 1997-1998
There are no significant differences among 1998-1999, 1999-2000, and 2000-2001

Student's t:

1997-1998, 1998-1999, 1999-2000, and 2000-2001 are significantly greater than Pre BMP
1998-1999, 1999-2000, and 2000-2001 are significantly greater than 1996-1997
1998-1999, 1999-2000, and 2000-2001 are significantly greater than 1997-1998
There are no significant differences among 1998-1999, 1999-2000, and 2000-2001

These results strongly indicate that BMP had an effect on turbidity, and somewhat indicate that this effect has plateaued over the last three rainy seasons (since the 1998-99 season).

For sediment, the same analytical procedure was applied, with different results (Table 3.10; Fig. 3.11). From the table and graph, we can reach the following conclusions at α = .05 (experimentwise for Tukey, individually for Student's t):

Tukey:
- 1999-2000 and 2000-2001 are significantly greater than Pre BMP
- 1999-2000 is significantly greater than 1996-1997
- 1999-2000 and 2000-2001 are significantly greater than 1997-1998

Student's t:
- 1998-1999, 1999-2000 and 2000-2001 are significantly greater than Pre BMP
- 1999-2000 is significantly greater than 1996-1997
- 1999-2000 and 2000-2001 are significantly greater than 1997-1998
- 2000-2001 is significantly less than 1999-2000

These results indicate that BMP had an effect on sediment, but either the 2000-01 season represents an anomaly, or the effects of BMPs are diminishing. It is possible that this is the beginning of a "plateau" effect as we saw with turbidity. This also indicates that a simple linear model may not be appropriate with future years' data.

Table 3.10. Summary of statistics of analysis of variance, dlogsed versus BMP Year.

Comparison	Difference	Standard Error	t-Value	Tukey p-value	Student's t p-value
(96-97) – Pre BMP	0.2187	0.11136	1.966	0.3717	0.0531
(97-98) – Pre BMP	0.1361	0.0978	1.391	0.7320	0.1684
(98-99) – Pre BMP	0.4458	0.2204	2.022	0.3400	0.0234
(99-00) – Pre BMP	0.7202	0.1180	6.105	0.0000	0.0000
(00-01) – Pre BMP	0.4365	0.1015	4.299	0.0007	0.0001
(97-98) – (96-97)	-0.0827	0.1076	-0.7681	0.9720	0.4449
(98-99) – (96-97)	0.2270	0.2250	1.0092	0.9135	0.1581
(99-00) – (96-97)	0.5015	0.1262	3.9730	0.0022	0.0002
(00-01) – (96-97)	0.2177	0.1110	1.9613	0.3743	0.0536
(98-99) – (97-98)	0.3097	0.2186	1.417	0.7169	0.1607
(99-00) – (97-98)	0.5842	0.1145	5.100	0.0000	0.0000
(00-01) – (97-98)	0.3004	0.0975	3.081	0.0332	0.0029
(99-00) – (98-99)	-0.2745	0.2284	1.2020	0.8345	0.2332
(00-01) – (98-99)	-0.0093	0.2203	-0.0422	1.0000	0.9665
(00-01) – (99-00)	-0.2838	0.1177	-2.410	0.1661	0.0184

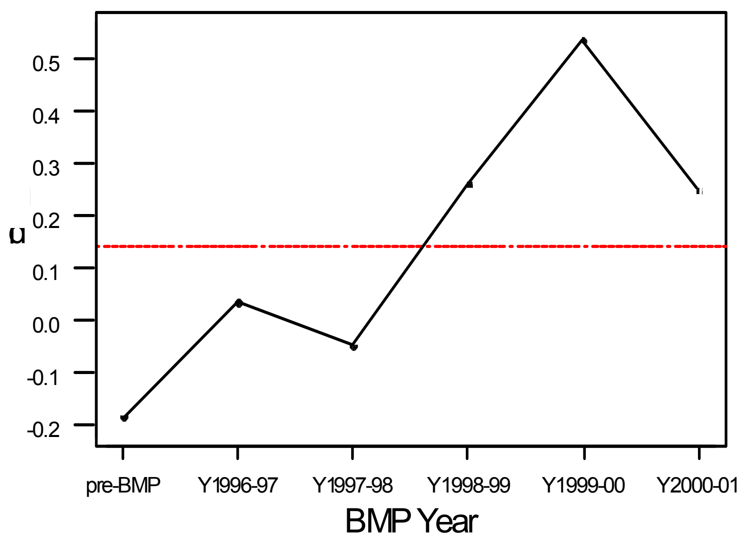


Figure 3.11. Graph of the sediment means being compared by analysis of variance.

Piecewise Linear Regression Model

Because of the results of prior analyses, we fit a piecewise linear regression model—one that allows the basic nature of the relationship to change at one or more points in time—to the turbidity dataset, at the maximum (1998-99), where the effects of BMPs might have plateaued. We modeled the change in the regression relationship to start a few days prior to the first storm in the 1998-1999 rainy season. The first storm was on the 994th day post-BMP; we allowed the model to change starting with the 990th day post-BMP. This model change was done by adding a new variable to the model. This new variable is an indicator or dummy variable for data after the 990th day multiplied by (*BMP Time* – 990). Basically, this allows for the line to be continuous, but with a different slope and Y-intercept starting on the 990th day (Neter et al., 1996) (Fig. 3.12). The test for normality indicated no significant problem with normality.

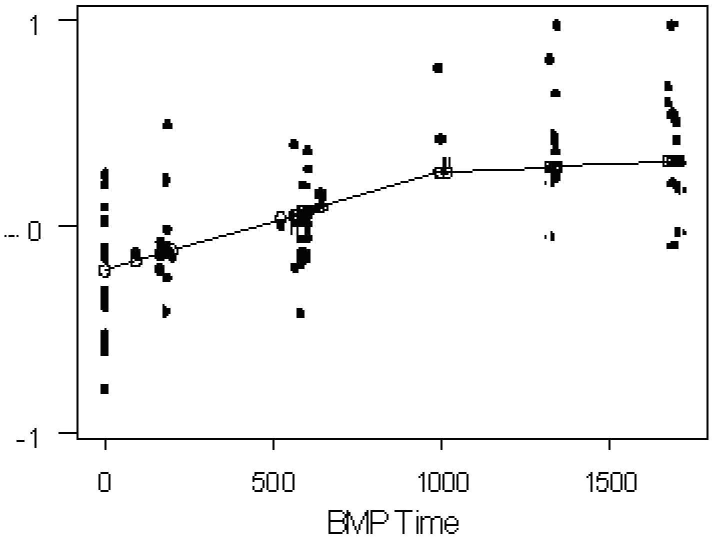


Figure 3.12. Piecewise linear regression analysis of *dlogturb* versus BMP Time.
The regression equation is dlogturb = - 0.217 +0.000479 BMP Time -0.000395 (BMPT_990)*Indi. R^2 = 40.9%.

A general linear test was used to determine if the slope for the last three years equaled zero (meaning there was no significant change over these three rainy seasons). The test failed to reject this hypothesis. While the process of failing to reject such a null hypothesis does not "prove" the result with any degree of confidence, it certainly leaves the idea that the effects have "plateaued out" as being feasible. As of 2000-01, testing was unable to reject the hypothesis that there is no difference in the regression model over the complete range of BMP Time—saying that it is also possible that the regression relation continues.

This model had the same problem as previous models—two outliers. With these deleted, a different relationship was obtained (Fig. 3.13), but with a higher R^2. With the outliers eliminated, there appears to be less of a plateau effect.

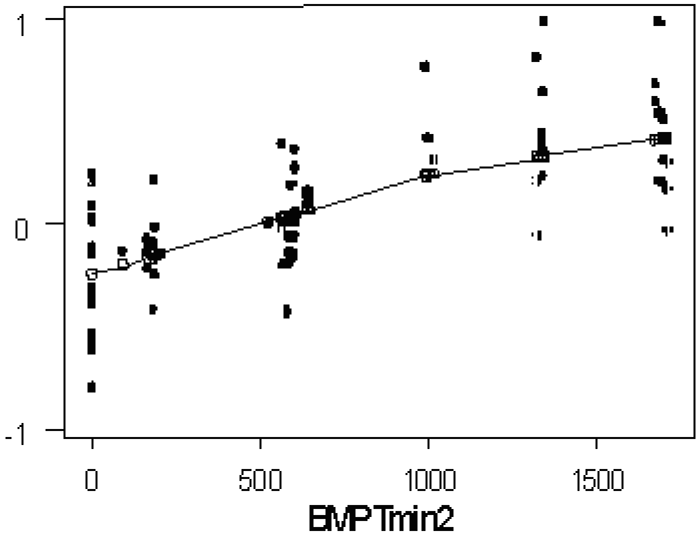


Figure 3.13. Piecewise linear regression analysis of *dlogturb* versus BMP Time, minus two strong outliers.
The regression equation is dlogtmn2 = - 0.247 +0.000486 BMPTmin2 -0.000232 B*Inmin2. R^2 = 56.5%.

Finally, an attempt was made to use streamflow differences between the two creeks to predict differences in log turbidity or differences in log sediment. No models attempted indicated that the difference in flows improved the predictions. Neither Chumash nor Walters flow was useful as a covariate to predict dlogturb. However, Chumash flow was successful in improving the prediction of dlogsed (Table 3.11).

Table 3.11. Regression Analysis: dlogsed versus BMP Time, cflowall

Weighted analysis using weights in N-f

The regression equation is
dlogsed = - 0.383 +0.000356 BMP Time + 0.0107 cflowall

Predictor	Coef	SE Coef	T	P
Constant	-0.3831	0.1187	-3.23	0.002
BMP Time	0.00035630	0.00006503	5.48	0.000
cflowall	0.010729	0.003923	2.73	0.009

S = 1.289 R-Sq = 37.0% R-Sq(adj) = 34.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	50.664	25.332	15.25	0.000
Residual Error	52	86.367	1.661		
Total	54	137.031			

Regression Model, Relationship of Sediment to Turbidity
By regression analysis, *dlogsed* was compared to *dlogturb* for each creek. The objective was to quantify the relationship between turbidity and suspended sediment. The relationships between these water quality parameters are very strong (Fig. 3.14 and 3.15), and show promise that turbidity, a rapid, reliable, and cost-effective measurement, is a good predictor for suspended sediment concentration.

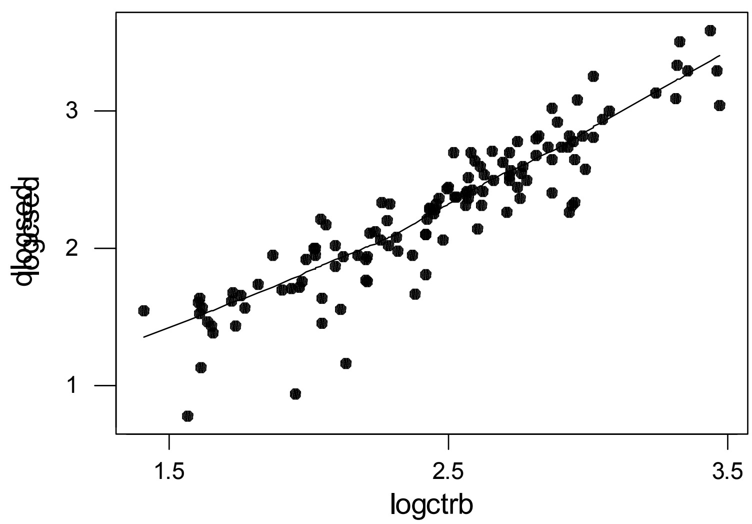


Figure 3.14. Log of Chumash suspended sediment mean versus log of Chumash turbidity mean with LOWESS line superimposed.
The regression equation is dlogsed = -0.371 + 1.09(dlogturb), R^2 = 83.9%.

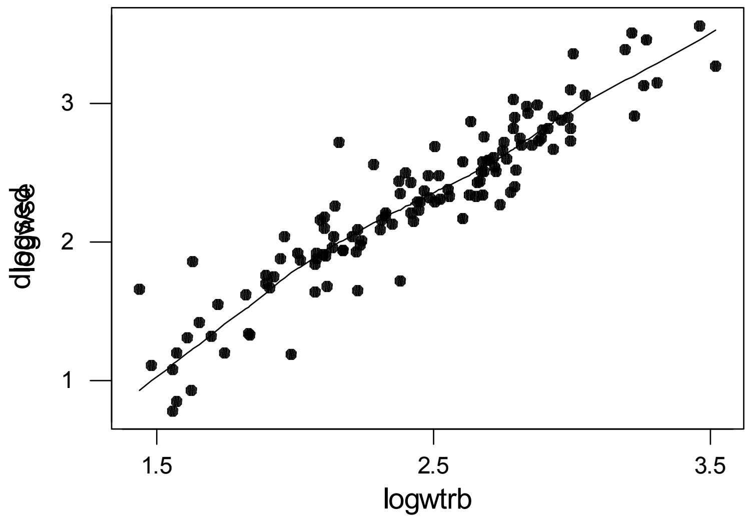


Figure 3.15. Log of Walters suspended sediment mean versus log of Walters turbidity mean with LOWESS plot superimposed.
The regression equation is dlogsed = -0.541+1.17(dlogturb), R^2 = 86.3%.

Major emphasis of water quality monitoring and analysis was on turbidity and suspended sediment. Conductivity was also monitored in the event-based study. Conductivity in Chumash and Walters Creeks showed the usual dilution effect during storms, with lower values during peak flows and higher values during low flow periods.

Significant Findings in Event-Based Water Quality Monitoring

Collection of streamflow data was challenging for a variety of reasons including; under designed flumes, occasional technological (software and hardware) breakdowns, and occasional operator errors in downloading data. The total effect of these challenges resulted in substantial gaps in flow data. Consequently, reliable values of sediment load were impossible to calculate.

Despite these difficulties, the linear modeling approach for evaluating differences in turbidity or suspended sediment collected from the paired watersheds has been determined successful in detecting water quality improvements.

Turbidity and suspended sediment concentration were used to show improvements in water quality. Both showed similar trends, Chumash Creek turbidity and suspended sediment decreased, compared to Walters, in small but significant increments following BMP implementation. Turbidity and suspended sediment concentration values were strongly correlated in the two streams. This correlation provides the potential of increasing the cost-effectiveness of future monitoring, by measuring turbidity frequently, and measuring suspended sediment concentration only if a threshold value (determined empirically) of turbidity is exceeded. This is discussed further in Chapters 9 and 10.

As stated earlier, a 50 % reduction in sediment from Chumash Creek was anticipated. Without sediment loads, calculation of a precise reduction is impossible. Efforts to test the anticipated sediment reduction, averaging event-based suspended sediment concentration for each year for each of the paired watersheds revealed an interesting trend in Chumash vs. Walters (Table 3.12, Fig. 3.16). Post-BMP Chumash sediment concentration steadily decreased, relative to pre-BMP Chumash, and also relative to Walters, during the monitoring period. Table 3.12 shows that the average pre-BMP sediment concentration values of Chumash and Walters (for each watershed, the average of the years 1994-95 and 1995-96) are close in value, in the range of 600 mg/L. The average post-BMP value for Chumash is about 262 mg/L, while the post-BMP value for Walters remained high, about 533 mg/L. Figure 3.17 shows the annual averages.

To conclude with certainty that the BMPs have reduced sediment by 50 percent is difficult for two reasons. Firstly, sediment concentration is highly dependent on streamflow, and precipitation and streamflow have been irregular throughout the monitoring period. Secondly, two years of pre-BMP monitoring were probably insufficient to give a strong picture of pre-BMP conditions. Nevertheless, this analysis of the sediment data appear to confirm the results found by regression analyses described above, and suggest that BMPs have reduced sediment from Chumash Creek.

Table 3.12. Average suspended sediment concentration, in milligrams per liter, each year of monitoring.

	Ave. mg/L, all events	
Year	Chumash Sed	Walters Sed
1994-95	841.8	916.4
1995-96	460.8	439.6
Average pre-BMP	**651.3**	**678**
1996-97	386.3	661.8
1997-98	345	396.5
1998-99	257.8	520.5
1999-2000	210.9	892
2000-01	108.8	195.6
Average post-BMP	**261.76**	**533.28**

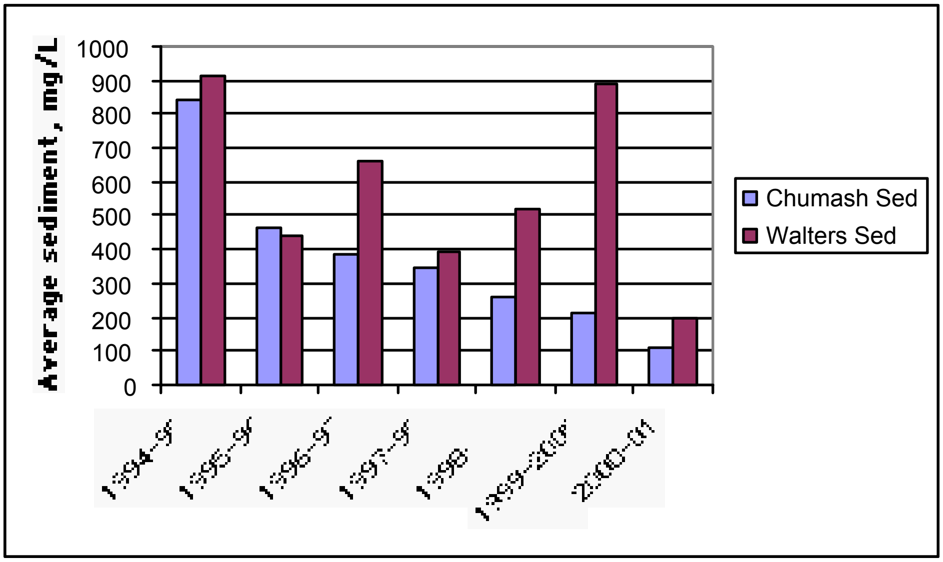


Figure 3.17. Average values of suspended sediment concentration, plotted by year. Data values are those in Table 3.12, above.